Lung Ultrasound in Acute Respiratory Failure

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KEYWORDS

• Lung ultrasound • Respiratory failure • Critical care • Intensive care • ARDS

KEY POINTS

- Lung ultrasound allows for real-time, repeatable, and radiation-free assessment of acute respiratory failure at the patient's bedside.
- Lung ultrasound offers high sensitivity and specificity in detecting a range of life-threatening pathologies, including pneumonia, pneumothorax, pleural effusions, and pulmonary edema.
- In critically ill patients, lung ultrasound is valuable for monitoring treatment response and guiding interventions.
- Incorporating lung ultrasound into the routine assessment of critically ill patients can enhance diagnostic accuracy.

INTRODUCTION

Prior to the 1980s, many saw lung ultrasound (LUS) as an oxymoron, with the high impedance mismatch between air and surrounding tissue making ultrasonographic assessment of lung parenchyma obsolete. However, led by Dr Daniel Lichtenstein, a LUS revolution was born as clinicians realized its unique potential in assessing critically ill patients.[1] Indeed, when one acknowledges that healthy lung tissue results in a characteristic pattern of artifacts, we can start to better interpret other findings analogous to common pathologies.[2–5]

Over the past 3 decades, our understanding and use of LUS have expanded rapidly, and many clinicians now view LUS as an invaluable tool in assessing critically unwell

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Crit Care Clin 41 (2025) 443–453

https://doi.org/10.1016/j.ccc.2025.02.001 **criticalcare.theclinics.com**

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Abbreviations	
ARDS	acute respiratory distress syndrome
CT	computed tomography
LUS	lung ultrasound
LUSS	lung ultrasound scoring system

patients presenting with acute respiratory failure.[2,5] Efficient use of LUS allows for a rapid, repeatable, and reliable assessment of the etiology of respiratory failure at the patient's bedside. It may also be combined with ultrasound assessments of other organ systems (eg, echocardiography or abdominal ultrasound), as part of a comprehensive full-body examination.[2,3,6]

In this article, we will introduce our preferred method to perform a LUS assessment in critically ill patients presenting with acute respiratory failure and highlight some of the key findings that may be used to identify common pathologies.

HOW TO PERFORM LUNG ULTRASOUND

Anatomy

One of the strengths of LUS is its simplicity to perform, even in patients in whom standard examinations may be anatomically or physiologically challenging. A basic understanding of thoracic anatomy is key to optimal performance and interpretation of LUS. The chest wall, from most superficial to deep, is composed of skin, subcutaneous tissue, and muscle.[2,7] The visceral pleura then lines the inner chest wall, separated from the parietal pleural by a thin layer of pleural fluid, which assists in the sliding of the two layers. When performing LUS, the pleura is normally visible as a bright hyperechoic line between ribs. Deep to this are the alveoli and lung parenchyma, normally not visible in LUS unless pathology is present. While LUS is both sensitive and specific for pulmonary pathology, it is important to acknowledge that it only provides a regional assessment of the lung at the point of scan; a thorough and systematic approach to scanning is therefore key.[4,8]

Choice of Probe

Low-frequency transducers (eg, the phased array transducer and the curvilinear transducer) are classically used to assess lung parenchyma due to their ability to image deep structures, while high-frequency transducers (eg, the linear transducer) allow for detailed assessment of more superficial pathology such as those affecting the pleura. The choice of probe is ultimately down to the clinician's preference, and the author's routine practice is to use the curvilinear probe for the assessment of lung parenchyma and the linear probe for the pleural assessment.[2,5,9] However, all probes may be utilized to perform LUS, and lack of availability of the preferred probe does not preclude the performance of a scan.

Performing the Scan

Multiple critical care LUS protocols currently exist, spanning from focused 6 point (one side: 3 points) regimens to 12 point (one side: 6 points) assessments, with no evidence demonstrating the superiority of one method over the other. In this article, we describe the most common critical care protocol used in the UK, the Focused Ultrasound in Intensive Care Lung protocol.[9] This consists of 6 total probe positions (3 on each side), specifically the right and left upper, right and left lower, and right and left postero-lateral regions. The authors' routine practice is to scan the high-yield areas

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first (eg, apex if a pneumothorax is suspected), sequentially comparing one area of the lung to the relevant position on the contralateral lung, as one would routinely do when auscultating the chest.[9]

At each point, the sonographer should assess for the presence of pleural sliding, the appearance of the pleural line, and aeration of the lung. The characteristic findings in healthy, well-aerated lungs are A-lines with pleural sliding.[1,2,9] A-lines refer to reverberation artifacts from the interface between US waves and healthy pleura, visible as hyperechoic, regularly spaced horizontal lines. When A-lines are combined with lung sliding, this represents an area of lung with preserved aeration. B-lines in contrast are vertical reverberations that occur when alveolar air is replaced by fluid.[8] These are explained in more depth in the Pathology sections. Diaphragmatic movement should then be assessed in the postero-lateral regions, where pleural effusions may be seen and even extend up to more apical windows if of sufficient size.[10] If present, effusions should be described by their size (eg, small, moderate, or large) and appearance (eg, complex vs simple).[10,11]

Any change in respiratory physiology should prompt consideration for a repeat scan, with the approach adapted to the pathology felt most likely. For example, if a pneumothorax is suspected, we recommend starting the examination using the linear probe in the most apical lung portion, while if a pleural effusion is suspected we would start in the postero-lateral area with a curvilinear probe.

IDENTIFYING PATHOLOGY

Normal Lung Ultrasound Findings

To accurately identify lung pathology on ultrasound, it is crucial to first understand normal LUS findings. A normal LUS is characterized by 2 key features: the sliding lung sign and the presence of A-lines. Unlike cardiac, abdominal, or vascular imaging—where artifacts may interfere with the image—LUS depends on these artifacts to differentiate normal structures from pathologic conditions.

In a normal LUS, lung sliding with horizontal A-lines is observed, while B-lines are absent (**Fig. 1**). The pleura appears as a smooth, thin, hyperechoic line that moves synchronously with respiration, a movement referred to as lung sliding, which is a key indicator of normal lung function. The presence of A-lines, which are horizontal

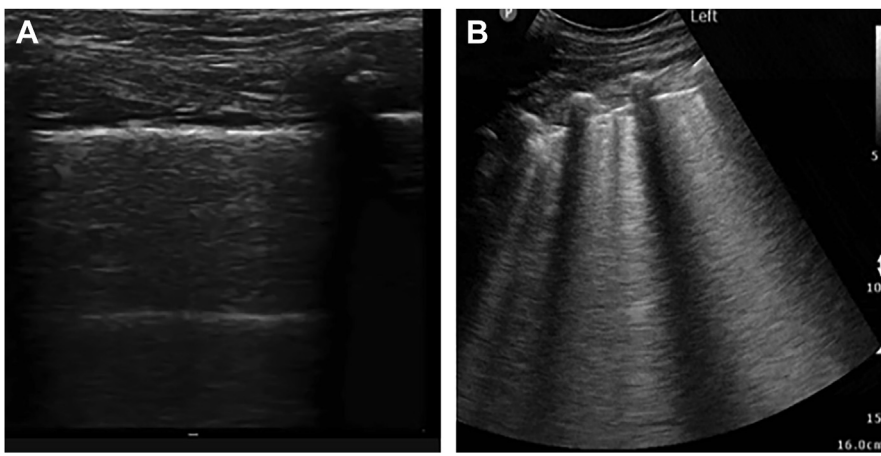

Fig. 1. Lung ultrasound demonstrating (*A*) A-lines in healthy lung. (*B*) B-lines in a patient with cardiogenic pulmonary edema.

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reverberation artifacts, further suggests the absence of significant interstitial or alveolar pathology.

Pneumothorax

The sensitivity and specificity of LUS for diagnosing pneumothorax surpass those of supine anteroposterior chest radiographs, making it an invaluable tool in the critical care setting.[12–14] A skilled sonographer may also be able to map out the borders of a pneumothorax to guide drainage and thus reduce the risk of complications.

Diagnosing a pneumothorax via ultrasound primarily involves identifying the absence of lung sliding. This finding is corroborated by the "barcode sign" or "stratosphere sign" on M-mode imaging (**Fig. 2**), which reveals a static pattern, in contrast to the dynamic "seashore sign" characteristic of normal lungs.[12,15] However, several other conditions may also present with absent lung sliding, including lung bullae, prior pleurodesis, right main bronchial intubation, or lung collapse.[12,16,17] Differentiation may be achieved by the identification of a "lung pulse" (absent in a pneumothorax) and the presence of a "lung point" (present in a pneumothorax).

The lung pulse refers to rhythmic oscillations of the pleural lining caused by cardiac systolic activity. The presence of a lung pulse excludes pneumothorax and can be observed in scenarios such as apnea (in patients with a pulse), one-lung ventilation, or diaphragmatic paralysis. In a true pneumothorax, the lung pulse will be absent.

A lung point is considered pathognomonic for pneumothorax. It represents the location where the visceral pleura begins to separate from the parietal pleura.[12–14] The transition between areas with and without lung sliding defines the lung point, which is nearly 100% specific for pneumothorax.[12,13,16] Additionally, visualization of the lung point allows for mapping out of the extent of a pneumothorax, aiding in size estimation.[16] This transition can also be confirmed on M-mode imaging, which demonstrates a shift from the seashore pattern to the barcode pattern.[12–14]

Pulmonary Edema

A-lines are seen in healthy lung tissue as horizontal, equidistant reverberation artifacts, suggests the absence of significant interstitial or alveolar pathology. In contrast, B-lines are hyperechoic vertical lines rising from the pleura that extend all the way down to bottom of image, and are caused by the reverberation artifact generated

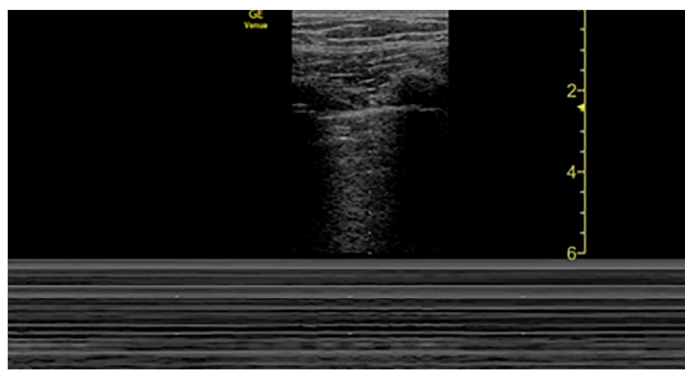

Fig. 2. Lung ultrasound with M-mode demonstrating the "stratosphere" or "barcode" sign in a patient with a pneumothorax.

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when ultrasound waves interact with fluid within the interlobular septa (see Fig. 1). They usually moves with lung sliding and represent the presence of fluid within the alveoli. B-lines may be present in cardiogenic pulmonary edema, as well as interstitial lung diseases and acute inflammatory pulmonary pathology (eg, acute respiratory distress syndrome [ARDS]).

Findings indicative of cardiogenic pulmonary edema on LUS include diffuse B-lines distributed bilaterally and symmetrically, along with a smooth pleural line, without features such as a shredded pleura, which are more typical of non-cardiogenic causes.[8,18] The "bat wing" distribution pattern or the presence of spared lung areas can further differentiate cardiogenic from non-cardiogenic etiologies. Complementary echocardiographic assessment of cardiac function can provide additional diagnostic confirmation and clarify the underlying cause.

Pneumonia

Ultrasound is a sensitive and specific diagnostic tool in pneumonia.[19,20] Characteristic findings include B-lines, consolidation with or without air bronchograms, or parapneumonic effusions.[7,21] These signs suggest the presence of fluid, cells, and other pathologic products within the alveoli and interstitial space. Dynamic air bronchograms (moving air within the bronchi in consolidated lung) are highly specific for pneumonia. Sonographic hepatization, where consolidated lung tissue appears to have a similar texture to the liver on ultrasound, is a hallmark of lung consolidation (Fig. 3).[20–22] This finding reflects the replacement of air-filled alveoli with fluid, exudate, or cellular debris, giving the lung a dense appearance.[7,21] Additionally, the posterolateral-spine sign, characterized by the visualization of the thoracic spine extending beyond the diaphragm on ultrasound, may indicate the presence of a pleural effusion or severe lung consolidation.[1,2,23]

Atelectasis

Similar to pneumonia, atelectasis is identifiable on ultrasound as areas of dense, consolidated lung tissue, typically appearing as a wedge-shaped hypoechoic region with limited respiratory movement.[2,19] In contrast to pneumonia, dynamic air bronchograms will not be visible in atelectatic lung.

Pleural Effusion

LUS is highly effective in identifying pleural effusions, offering greater sensitivity and specificity than commonly used imaging modalities such as chest radiography and

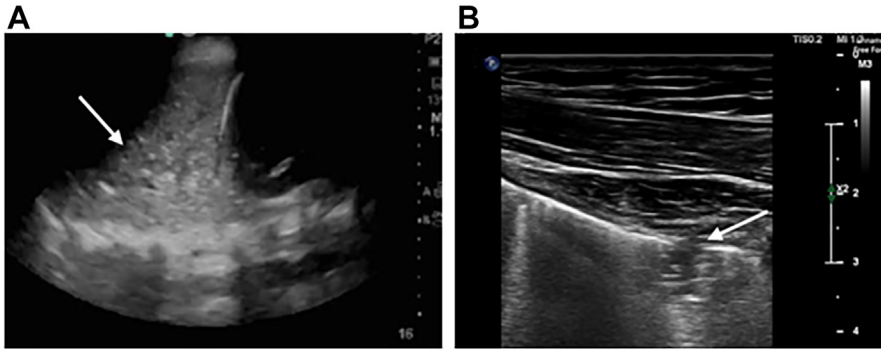

Fig. 3. (*A*) Hepatization of lung tissue in a patient with severe pneumonia (*arrow*). (*B*) Subpleural consolidations in a patient with COVID-19 (*arrow*).

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computed tomography (CT).[24,25] Pleural fluid typically appears as an anechoic or hypoechoic space between the parietal and visceral pleura and can be either free-flowing or loculated (Fig. 4).[5,24,25] Diagnostic features such as the "quad sign" and "sinusoid sign" can confirm the presence of pleural effusion.[26] The "quad sign" refers to the identification of 4 borders—pleural line, ribs, and the lung line—enclosing the anechoic pleural fluid. The "sinusoid sign," seen on M-mode, demonstrates a dynamic, sinusoidal movement of the lung line toward the chest wall with respiration, confirming the presence of free-flowing pleural fluid.[23]

For a comprehensive evaluation, both B-mode and M-mode ultrasound should be employed to assess the location, size, and characteristics of pleural effusions. B-mode imaging is essential for determining the nature of the effusion (eg, simple vs complicated), while M-mode provides insights into the respirophasic motion of the fluid and atelectatic lung, aiding in the differentiation of transudative and complicated effusions.

Key anatomic landmarks are crucial for identifying pleural effusions, with the liver serving as a reference point on the right and the spleen on the left. Imaging should extend cephalad to the diaphragm to assess both the pleura and lungs thoroughly. The ultrasound appearance of the fluid and pleura can help predict the underlying etiology of pleural effusions.

Simple effusions typically present as anechoic fluid without septations or internal debris. Conversely, complicated effusions may exhibit features such as internal debris, septations, fibrin deposits, or loculations. Pleural masses or thickening are additional findings that may indicate an exudative process.[11,25] The "plankton sign," characterized by the swirling movement of echogenic particles within an anechoic pleural effusion due to cardiac and respiratory activity, is highly indicative of a complicated effusion and generally rules out a transudative cause.[2,23]

Acute Respiratory Distress Syndrome

Over the past 2 decades, LUS has become a proven, sensitive, and specific method for identifying morphologic patterns associated with ARDS, showing strong reproducibility when compared to CT imaging.[27,28] In ARDS, LUS commonly reveals diffuse bilateral B-lines, reflecting severe interstitial edema. These findings may appear patchy and often coexist with areas of normal aeration or consolidation. LUS is valuable for evaluating the extent of lung involvement and tracking responses to

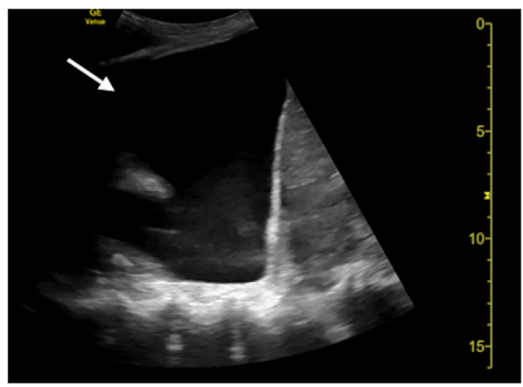

Fig. 4. A large simple pleural effusion.

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therapeutic interventions. Its dynamic nature also allows for real-time guidance in adjusting ventilatory settings, improving respiratory management.

In the early stages of ARDS, focal B-lines are the predominant feature. As the condition progresses, characteristic findings include thickened pleural lines, multiple or fused B-lines, and heterogeneous subpleural consolidations. Recent research has introduced lung ultrasound scoring system (LUSS) to evaluate early ARDS changes and predict disease severity and progression.[29] LUSS assesses lung aeration across 12 thoracic regions, providing insights into aeration changes before intubation and after therapeutic interventions in mechanically ventilated patients. Scoring for each region is based on sonographic aeration patterns (**Fig. 5**).[29]

CHEST DRAIN INSERTION

LUS is now widely considered the standard of care for procedures such as pleural aspiration, pleural biopsy, chest tube placement for pleural fluid drainage, pneumothorax management, and endocavitary drug instillation.[5,24,30] Ultrasound guidance enhances procedural accuracy and significantly reduces the risk of complications.[5,30]

Equipment and Preparation

A convex or cardiac probe (2.5–5 MHz) is recommended. The choice between a chest tube or a pigtail catheter depends on the clinical diagnosis. Larger-bore chest tubes are preferred for empyema or hemothorax, while a pneumothorax may only require a small-bore chest tube.

Before the procedure informed consent should be obtained where possible, and coagulopathy should be evaluated. For patients on anticoagulants, bleeding risks should be assessed. Optimal patient positioning is key, the specifics of which will depend on the patient's clinical condition: supine or erect for stable patients, or as feasible in ventilated patients in the ICU. The optimal position can then be confirmed using ultrasound guidance.

Procedure Steps

Preparation

- Sterilize the area using standard protocols, and ensure the use of a sterile probe cover.
- Identify the pleural effusion on ultrasound, mapping the structures from the skin to the fluid pocket. To minimize the risk of lung injury or pneumothorax, target an anechoic pocket that is at least 1.5 cm in depth.
- Ultrasound may be used to mark the optimal site for drainage or to provide real-time guidance, depending on operator experience and preference.

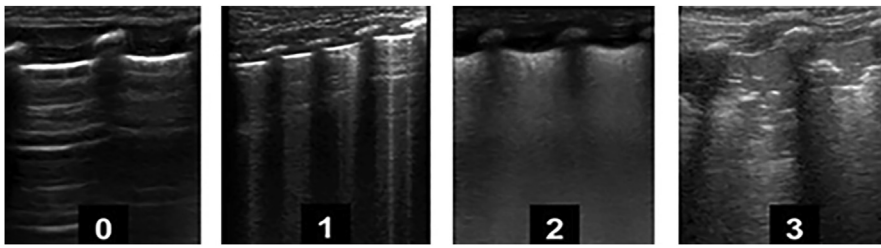

Fig. 5. Progressively reduced lung aeration (0–3) visible in worsening ARDS.

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Anesthesia

- Administer a local anesthetic to numb the skin, subcutaneous tissues, deeper layers, and intercostal muscles.

Needle insertion

- Insert the needle into the pleural space, taking care to avoid the lower border of the upper rib to reduce the risk of neurovascular injury.
- Confirm needle placement by aspirating fluid.

Catheter placement

- Introduce a guidewire through the needle and verify its position using ultrasound.
- Advance a dilator over the guidewire to create an opening for the catheter. A scalpel may be required for this step.
- Insert the pigtail catheter using the Seldinger technique, then remove the guidewire.
- Attach the catheter to a 3 way stopcock and drainage system.
- Confirm the catheter placement with ultrasound, secure it using surgical sutures, and perform a post-procedure chest radiograph to identify potential complications.

Post-procedure assessment

- Use LUS to evaluate the progression or resolution of the pathology following chest drain insertion.

DISCUSSION

In recent years, LUS has seen a rapid increase in use among critically ill patients.[2,22] This growth is likely somewhat driven by the rising availability of ultrasound machines in critical care units worldwide and the increasing prevalence of hand-held portable devices. LUS offers numerous advantages over alternative imaging techniques, including improved sensitivity and specificity compared to thoracic auscultation, chest radiography, and CT for many conditions. Additionally, it eliminates the need to transfer critically ill patients to remote areas of the hospital for diagnostic imaging, or expose them to ionizing radiation.

There is strong advocacy for integrating LUS into both post-graduate and, potentially, undergraduate medical training curricula. In the UK, where one of the authors is based, the primary challenge to such integration is the limited number of accredited trainers. However, efforts are underway to address this gap and expand access to training in critical care ultrasound.[31]

Despite its advantages, it is important to acknowledge the limitations of LUS. One notable limitation is the training required to achieve proficiency. Nevertheless, LUS is relatively straightforward to learn compared to more complex ultrasound modalities, such as echocardiography. While LUS demonstrates high sensitivity for many pathologies, its specificity can be low. For instance, an inexperienced operator might misinterpret the absence of pleural sliding due to a collapsed lung as a pneumothorax. Thus, LUS findings must always be interpreted in the context of the clinical picture, serving as an extension of the physical examination rather than a replacement.

Another commonly cited limitation is related to governance and quality assurance. Unlike chest radiographs or CT scans, LUS images are often not routinely stored or readily accessible for review. Addressing this issue will require better education and

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the establishment of robust local governance structures.[22,32] However, implementation is likely to be challenging, constrained by the availability of time, trainers, and resources. Overall, while LUS holds significant promise, its effective integration into practice depends on addressing these challenges through education, structured training, and resource investment.

SUMMARY

In recent decades, LUS has gained prominence as a valuable tool for assessing patients with acute respiratory failure. Its simplicity, high diagnostic accuracy, and bedside applicability make it an appealing imaging modality. Compared to other skills acquired during medical training, LUS is neither overly complex nor particularly time-consuming, yet it offers superior diagnostic capabilities. While stethoscopes may not quite be ready to be cast away as mere wheeze detectors, to not embrace LUS is to reject a significant step forward in medical technology and deny our patients this progress.

CLINICS CARE POINTS

- LUS can be performed at the patient's bedside, making it especially useful for critically ill patients who cannot be safely transported for imaging.
- LUS provides superior diagnostic accuracy for acute respiratory failure compared to traditional tools like thoracic auscultation and radiography.
- LUS offers a safe alternative to imaging modalities that expose patients to ionizing radiation, such as X-rays or CT scans.
- Integrating LUS into clinical practice represents a significant step forward in technology-driven diagnostics, complementing and enhancing traditional tools like the stethoscope.

DISCLOSURE

None to declare.

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